Light Structures for Automotive Vehicles

ISEP, Porto Portugal
Outline

- Introduction
- Materials in vehicles
- Polymers
- Polymer composites
- Thermosetting based composites
- Thermoplastic based composites
- Natural fibre composites
- Future materials and technologies
GDP - Gross Domestic Product; total value of goods and services produced over a period of time

Introduction

Vehicle use will expand globally. (data estimated from the U. S. Dep. of Energy)

Higher vehicle weight means higher fuel consumption.

Small size vehicles are not what the consumer wants

Introduction
Vehicle weight and performance are two of the most important engineering parameters that determine a vehicle's fuel economy.

All other factors being equal, higher vehicle weight (which supports new options and features) and faster acceleration performance, both decrease a vehicle's fuel economy.

Average vehicle weight and performance had increased steadily from the mid-1980s through 2004.

Introduction

Vehicles represent 0.4% of global CO₂ emissions

Global CO₂ emissions per year

- Total CO₂ emissions approx. 800 Gt per year
- Burning of biomass < 1%
- Vegetation 27%
- Oceans 41.5
- Soil 27%
- Anthropogenic CO₂ emissions 35%


Development of global anthropogenic CO₂ emissions

- Anthropogenic CO₂ emissions total 28 Gt per year
- Air traffic 3%
- Other traffic 2%
- Ships on the high seas 1.5%
- Power stations 25%
- Burning of biomass 15%
- Passenger cars 5.5%
- Domestic fuel and small consumers 23%
- Trucks 6%
- Industry 19%

Today, climate and environment are two major inputs in the design process of a product, specially in the automotive industry.

**Source:** Materials and Design: The Art and Science of Material Selection in Product Design
Materials in vehicles

Reduction of vehicle CO\(_2\) emissions

System analysis results for representative models, without mass reduction

Simulating several technology packages that could be applied to major classes of vehicles in order to reduce CO\(_2\) emissions (fuel consumption)

Source: DeCicco presentation, Sebastian Vicuna, a report on the international vehicle technology symposium, 2004.
Materials in vehicles

Reduction of vehicle CO₂ emissions

System analysis results for representative models, with mass reduction

Simulating several technology packages that could be applied to major classes of vehicles in order to reduce CO₂ emissions (fuel consumption)

Source: DeCicco presentation, Sebastian Vicuna, a report on the international vehicle technology symposium, 2004.
Where does a car’s gasoline go?

- 6% accelerates the car, < 1% moves de driver
- Three-fourths of the fuel use is weight related
- Each unit of energy saved at the heels saves 7-8 units of fuel in the tank (or 3-4 with a hybrid)
- So **FIRST MAKE THE CAR RADICALLY LIGHTER-WEIGHT!**

Materials in vehicles

Driving forces for transportation industry

Motivation for new materials

- Government regulations for emissions and fuel economy
- Technological advances
- Market trends

Vehicle mass reduction
Changes in basic vehicle architecture
Power train

Reduction of vehicle weight by reducing vehicle size reduces functionality and contradicts market trends. Keep volume of space and meet fuel economy standards requires the use of new lighter materials.
Challenges and opportunities by introducing new materials

<table>
<thead>
<tr>
<th>Key parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance in intended function</td>
</tr>
<tr>
<td>Total cost</td>
</tr>
<tr>
<td>Design rules</td>
</tr>
<tr>
<td>Manufacturing feasibility at production volumes</td>
</tr>
<tr>
<td>Joining (welding, bonding …) time to qualify new materials, durability, reliability, crash energy management</td>
</tr>
</tbody>
</table>

- New processing methods
- Understand material properties
- New design rules
- Recycling

Aluminium
Magnesium alloys
Polymer composites

Materials in vehicles

Automotive Light weighting Materials

• Largest Focus Areas
  - Aluminum and magnesium casting
  - Aluminum sheet formation and fabrication
  - Polymeric-matrix composites processing

• Smaller Focus Areas
  - Aluminum and magnesium metal production
  - Metal-matrix composites
  - Titanium metal production and fabrication
  - Steel
  - General manufacturing (e.g., joining, NDE, IT)
  - Glazing (glass)
  - Crashworthiness
  - Recycling

Relative materials properties & costs

Source: David R. Cramer et al., Design and Manufacture of an Affordable Advanced-Composite Automotive Body Structure.
Ecology and safety as a driving force in the development of vehicles
Radom, 2-15/3/2008, Poland

Materials in vehicles

Materials in vehicles

Measures to realise lightweight constructions

- Material Lightweight Construction
  - Unreinforced and reinforced plastics
  - Aluminium magnesium
  - High-strength steels
  - Metal foams

- Structural Lightweight Construction
  - Tailored blanks/patchwork
  - Profiles/tubular structures
  - Optimised joint design
  - New structures and complex geometries

- Optimising of Production Process
  - Reduced number of spot welds
  - Light joining techniques
  - New manufacturing processes (e.g. hydroforming)

Examples of different types of body structures

Steel Unibody (BMW 7er series)
- DC06 (120 MPa)
- DC04140
- ZStE180
- ZStE220
- ZStE260
- ZStE300
- ZStE380
- ZStE420
- CP800

Multimaterial Unibody (Aston Martin Vanquish)
- Outer skin: hot worked aluminium sheet
- Body platform: bonded aluminium sections
- Centre tunnel, A-pillar and roof frame: carbon fibre reinforced plastic
- Side sections, luggage compartment floor, crash structures: fibreglass reinforced plastic

Aluminium Space Frame (Audi A8)

Steel Space Frame (TKS)

Magnesium Space Frame (VW)

The application of polymers is growing in vehicles

<table>
<thead>
<tr>
<th>Polymers used in automotive industry</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Growth of polymers in cars through substitution: CAGR 3% (1975-2005, share of total weight)</strong></td>
</tr>
<tr>
<td><strong>Source:</strong> BAYER, 2006.</td>
</tr>
</tbody>
</table>
### Polymers with short fibre reinforcement

<table>
<thead>
<tr>
<th>Units</th>
<th>Tensile Strength</th>
<th>Tensile Modulus</th>
<th>Notched Izod Impact</th>
<th>Heat Deflection Temp. (264 psi)</th>
<th>Shrink</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC</td>
<td>8.5</td>
<td>320</td>
<td>15</td>
<td>270</td>
<td>.006 - .009</td>
</tr>
<tr>
<td>30% glass fibre PC</td>
<td>18.0</td>
<td>1200</td>
<td>3.0</td>
<td>N/A</td>
<td>.001 - .003</td>
</tr>
<tr>
<td>30% carbon fibre PC</td>
<td>23.0</td>
<td>2800</td>
<td>2.0</td>
<td>N/A</td>
<td>.0005 - .001</td>
</tr>
<tr>
<td>Nylon 6/6 unfilled</td>
<td>12</td>
<td>400</td>
<td>1.0</td>
<td>150</td>
<td>.015</td>
</tr>
<tr>
<td>Nylon 6/6 30% glass fibre</td>
<td>23.0</td>
<td>1350</td>
<td>1.5</td>
<td>486</td>
<td>.002 - .011</td>
</tr>
<tr>
<td>Nylon 6/6 20% aramid fibre</td>
<td>13.5</td>
<td>700</td>
<td>0.7</td>
<td>300</td>
<td>.010 - .015</td>
</tr>
<tr>
<td>Nylon 6/6 30% carbon fibre</td>
<td>35</td>
<td>3,300</td>
<td>1.8</td>
<td>485</td>
<td>.0005 - .002</td>
</tr>
</tbody>
</table>

**Short glass fibres**: used to strengthen the polymer and reduce creep. Fibres typically measure 10 to 15 microns in diameter and vary in length from 1.6 mm to 6.5 mm.

**Carbon fibre**, used to strengthen a composite and also to aid in static dissipation.

**Minerals**, such as talc and clay, often used as fillers to reduce the cost of finished parts and also reduce warping.

Polymers with short fibre reinforcement can be processed by injection moulding.
Polymer composites

Compared to traditional vehicle materials composites offer:

<table>
<thead>
<tr>
<th>Better internal damping</th>
<th>Reduced tooling cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leads directly to reduced noise and vibration</td>
<td>Composite tooling cost is only 40% of steel stamping tooling cost</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Substantial weight reduction</th>
<th>Unrivalled corrosion resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRP composites are typically 25-35% lighter than steel parts of equal strength</td>
<td>Few materials offer better corrosion resistance than FRP composites in any application, automotive or otherwise</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unparalleled damage resistance</th>
<th>Improved design flexibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Damage resistance of composites is far superior to that of aluminium and steel panels</td>
<td>Moulding offers shape complexity, geometry details, and a depth-of-draw range unavailable with metal stamping; in some cases, a part just can’t be manufactured out of other materials</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lowered manufacturing complexity</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fewer parts required for a finished assembly cuts manufacturing costs and often speeds run-up to design completion and model introduction</td>
<td></td>
</tr>
</tbody>
</table>

Source: Supplement to ward’s autoWorld, composites multiple strengths infinite possibilities.
A composite material is a macroscopic combination of two or more distinct materials with a recognizable interface between them.


Diagram: 
- **Matrix**: Thermoplastic (Fusible) - Nylon, PP, PET/PBT, ABS, PC, PPO, PPS; Thermoset - Polyester, Vinyl Ester, Epoxy, Phenolic, Glass, Aramid, Carbon, Natural Fibres.
- **Reinforcement**: Particulate filler, Discontinuous fibers or whiskers, Continuous fibers, Particulate composite, Unidirectional discontinuous fiber composite, Unidirectional continuous fiber composite, Randomly oriented discontinuous fiber composite.
- **Composite**: Quasi-isotropic composite, Multidirectional continuous fiber composite.
Randomly oriented short fibre reinforcement

Randomly Oriented Short Fiber Reinforcement

**Elastic Properties:**
- $E$ = Young’s Modulus
- $G$ = Shear Modulus
- $\nu$ = Poisson’s Ratio

**Strength:**
- $\sigma_Y$ = Yield Strength
- $\sigma_U$ = Ultimate Strength

Therefore, properties are independent of orientation.
Unidirectional continuous fibre reinforcements

Material is Orthotropic, not Isotropic

Elastic Properties:
- $E_1 = \text{Longitudinal Young's Modulus}$
- $E_2 = \text{Transverse Young's Modulus}$
- $G_{12} = \text{In-plane shear Modulus}$
- $\nu_{12} = \text{Major Poisson's Ratio}$

Strength:
- $S_L = \text{Longitudinal Strength}$
- $S_T = \text{Transverse Strength}$
- $S_{LT} = \text{Shear Strength}$

Properties depend on orientation
Mechanical properties depend on fibre angle

For the data
- $E_L = 42748 \text{ MN/m}^2$
- $E_T = 8016 \text{ MN/m}^2$
- $G_LT = 4430 \text{ MN/m}^2$
- $\nu_{LT} = 0.264$

Ex from equation 20
Ey from equation 21

Source: Design data fibreglass composites, 1984.
Mechanical properties depend on fibre fraction

\[ E = E_f v_f + E_p (1 - v_f) \]
\[ X = X_f v_f + X_p (1 - v_f) \]

**Law of mixtures**

- **E**, Young modulus
- **X**, mechanical strength
- **p**, polymer property
- **f**, fibre property
- **v**, volume fraction

Source: Design data fibreglass composites, 1984.
### Typical properties of reinforcement fibres

<table>
<thead>
<tr>
<th>Property</th>
<th>Units</th>
<th>Glass</th>
<th>Carbon</th>
<th>Aramid</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>E</td>
<td>S</td>
<td>R</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>-</td>
<td>2.56</td>
<td>2.49</td>
<td>2.58</td>
</tr>
<tr>
<td>Specific heat</td>
<td>kJ/kg K</td>
<td>0.9</td>
<td>0.73</td>
<td>-</td>
</tr>
<tr>
<td>Tensile strength*</td>
<td>GPa</td>
<td>3.6</td>
<td>4.5</td>
<td>4.4</td>
</tr>
<tr>
<td>Young modulus*</td>
<td>GPa</td>
<td>76</td>
<td>86</td>
<td>85</td>
</tr>
<tr>
<td>Thermal expansion coefficient*</td>
<td>10^{-6}/°C</td>
<td>4.9</td>
<td>-1.3</td>
<td>-0.6</td>
</tr>
<tr>
<td>Thermal conductivity*</td>
<td>W/m·K</td>
<td>1.04</td>
<td>7-28</td>
<td>7-10</td>
</tr>
<tr>
<td>Specific strength*</td>
<td>KNm/kg</td>
<td>1400</td>
<td>1800</td>
<td>1700</td>
</tr>
<tr>
<td>Specific modulus*</td>
<td>MNm/kg</td>
<td>29.6</td>
<td>34.5</td>
<td>32.9</td>
</tr>
<tr>
<td>Fibre diameter</td>
<td>µm</td>
<td>3-20</td>
<td>8-13</td>
<td>5-24</td>
</tr>
</tbody>
</table>

* Properties in fibre direction

### Typical properties of common polymeric matrices

<table>
<thead>
<tr>
<th>Property</th>
<th>Units</th>
<th>Cured polyester</th>
<th>Cured epoxide</th>
<th>PEEK</th>
<th>PP</th>
<th>PC</th>
<th>Nylon 66</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>-</td>
<td>1,1-1,5</td>
<td>1-1,4</td>
<td>1,3</td>
<td>0,905</td>
<td>1,15</td>
<td>1,14</td>
</tr>
<tr>
<td>Specific heat</td>
<td>kJ/kg·K</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2,0</td>
<td>1,2</td>
<td>1,7</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>MPa</td>
<td>42-91</td>
<td>28-91</td>
<td>62</td>
<td>33</td>
<td>65</td>
<td>70</td>
</tr>
<tr>
<td>Flexural modulus</td>
<td>GPa</td>
<td>2-4,5</td>
<td>2-4</td>
<td>3,8</td>
<td>1,5</td>
<td>2,8</td>
<td>2,8</td>
</tr>
<tr>
<td>Deformation at break</td>
<td>%</td>
<td>4</td>
<td>0,6</td>
<td>4</td>
<td>150</td>
<td>100</td>
<td>60</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>W/m·K</td>
<td>0,21</td>
<td>0,21</td>
<td>-</td>
<td>0,20</td>
<td>0,2</td>
<td>0,24</td>
</tr>
<tr>
<td>Processing temperature</td>
<td>ºC</td>
<td>room-250</td>
<td>room-300</td>
<td>385</td>
<td>204</td>
<td>270</td>
<td>260</td>
</tr>
<tr>
<td>Service temperature</td>
<td>ºC</td>
<td>65</td>
<td>&gt;120</td>
<td>177-315</td>
<td>120</td>
<td>120</td>
<td>65-177</td>
</tr>
</tbody>
</table>

**Source:** PLASCAMS Database, Rapra Technology Lda., U. K., 1998.
Specific stiffness and strength of a variety of Polymer Matrix Composites in comparison to some metallic materials: $\Phi$ is the fibre volume fraction, $\rho$ is density, CFRP is carbon-fibre-reinforced polymer, GFRP is glass-fibre-reinforced polymer, UD is unidirectional, and QI denotes quasi-isotropic.
Ecology and safety as a driving force in the development of vehicles
Radom, 2-15/3/2008, Poland

Composite material routes

Ecology and safety as a driving force in the development of vehicles
Radom, 2-15/3/2008, Poland

Polymer composites

Specific properties/cost/cycle time

The position of composite technologies in terms of performance and production volumes.
Polymer composites

Composite material in the automotive market

<table>
<thead>
<tr>
<th>Density (g/cm³)</th>
<th>Strength (MPa)</th>
<th>Modulus (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Automotive Steel</strong></td>
<td>7.85</td>
<td>400-1300</td>
</tr>
<tr>
<td>6061 Aluminum</td>
<td>2.68</td>
<td>200-275</td>
</tr>
<tr>
<td>Glass Fibre Composite</td>
<td>1.49</td>
<td>200-700</td>
</tr>
<tr>
<td>Carbon Fibre Composite</td>
<td>1.27</td>
<td>400-1000</td>
</tr>
</tbody>
</table>

**ADVANTAGES**

- Less expensive tooling
- Parts integration
- Net shape forming
- No corrosion
- Energy absorption (polymer composite structures in the front end of a vehicle can lightweight without compromising safety)

**DISADVANTAGES**

- Raw material cost
- Repair processes
- Processing methodologies
- Recyclability (thermosetting matrix)
- Design database

### Properties of composite materials per industry

<table>
<thead>
<tr>
<th>Life Cycle</th>
<th>Aeronautics</th>
<th>Automobiles</th>
<th>Railways</th>
<th>Building</th>
<th>Industrial Engineering</th>
<th>Shipbuilding</th>
<th>Medicine</th>
<th>Electricity</th>
<th>Sports &amp; recreation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rigidity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical strength</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fatigue strength</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Corrosion resistance</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leak tightness</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Safety</th>
<th>Aeronautics</th>
<th>Automobiles</th>
<th>Railways</th>
<th>Building</th>
<th>Industrial Engineering</th>
<th>Shipbuilding</th>
<th>Medicine</th>
<th>Electricity</th>
<th>Sports &amp; recreation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shock resistance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fire resistance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat insulation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric insulation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shock and vibration damping</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Design</th>
<th>Aeronautics</th>
<th>Automobiles</th>
<th>Railways</th>
<th>Building</th>
<th>Industrial Engineering</th>
<th>Shipbuilding</th>
<th>Medicine</th>
<th>Electricity</th>
<th>Sports &amp; recreation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integration of functions</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complex shapes</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electromagnetic wave transparency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lighter structures</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Source:** The French industry of composite materials: priority challenges for sustainable development, DiGITIP Study, 2001.
Western European composites finished product tonnage by sector

<table>
<thead>
<tr>
<th>Sector</th>
<th>k tonnes</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerospace/Defence</td>
<td>104</td>
<td>6.8%</td>
</tr>
<tr>
<td>Industrial</td>
<td>150</td>
<td>9.7%</td>
</tr>
<tr>
<td>Construction</td>
<td>324</td>
<td>21.0%</td>
</tr>
<tr>
<td>Consumer</td>
<td>157</td>
<td>10.2%</td>
</tr>
<tr>
<td>Corrosion</td>
<td>90</td>
<td>5.8%</td>
</tr>
<tr>
<td>Electrical/Electronic</td>
<td>150</td>
<td>9.7%</td>
</tr>
<tr>
<td>Marine</td>
<td>80</td>
<td>5.2%</td>
</tr>
<tr>
<td>Transportation</td>
<td>485</td>
<td>31.5%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1540</strong></td>
<td></td>
</tr>
</tbody>
</table>
Ecology and safety as a driving force in the development of vehicles Radom, 2-15/3/2008, Poland

Polymer composites

Composite/steel manufacturing costs

For high annual production volumes, steel is nowadays the most competitive material

industrial sectors and related driving forces for composite materials

Polymer composites

Composite in aviation

777=10% composite
787=50% composite

## Thermosetting based composites

### Thermosetting processing technologies

<table>
<thead>
<tr>
<th>Process Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Open mould</strong></td>
<td>hand lay-up &amp; spray-up</td>
</tr>
<tr>
<td><strong>Compression moulding</strong></td>
<td>SMC (&amp; Preform)</td>
</tr>
<tr>
<td><strong>Closed mould</strong></td>
<td>RTM, Infusion (SCRIMP), RIM &amp; S-RIM</td>
</tr>
<tr>
<td><strong>Filament winding</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Autoclave</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Pultrusion</strong></td>
<td></td>
</tr>
</tbody>
</table>

Composite possessing technologies with potential for automotive applications

Process development for automotive composite parts

Source: Georgia Institute of technology.
Thermosetting based composites

Hand lay-up and spray lay-up

**Hand lay-up**: a process wherein the application of resin and reinforcement is done by hand onto a suitable mould surface. The resulting laminate is allowed to cure in place without further treatment.

Hand lay-up cycle time can be reduced by using spray guns. The roving is fed into a chopper on the spray gun and the resulting strands are blown into a stream of liquid resin.

*Source*: J. S. Colton, Georgia Institute of Technology.

This manufacturing process allows to produce structural components of virtually any size or geometry.
Car componentes made from hand lay-up

Car prototype (limited production). 34 piece composite body car panels were produced using hand lay-up and RTM

Source: Exclusive motor cars.
SMC is a type of a fibre reinforced plastic which primarily consists on a thermosetting resin, a glass reinforcement and a filler. It is transformed from it’s liquid fibre and powdered ingredients into a sheet product by compression moulding.

- Cut the SMC paste into pieces with the desired length/weight
- Place it into the heated the mould cavity
- Close the mould and apply the curing cycle:
  pressure: 50 to 80 bar
  temperature: 120 to 160 °C
  cycle time: 30 to 150 s
- Demolding/part extraction

Source: SMC design manual, the composites institute of the society of plastic industry Inc, 1991.
SMC parts are widely used in the automotive industry for shock absorbers, cylinder head covers and engine bonnets.

VW added a medium-high roof on composite automated production to its T5 transporter series.
With **RTM**, the mould cavity is feed with resin under moderately high flow rate and pressure that is only limited by the structural ability of the moulding tool and perimeter clamping or press system to sustain mould closure. Working within these concerns, we then will build RTM tooling and clamping systems with structure great enough to sustain the flexing caused by the highest expected injection pressure during the moulding cycle.

**ADVANTAGES**
- Good surface quality of the produced parts
- Tooling flexibility
- Large, complex shapes can be produced
- Ribs, cores and inserts can be inserted
- Parts integration
- Range of available resin systems
- Range of reinforcements
- Controllable fibre volume fraction

**DISADVANTAGES**
- Low/medium production rates
- Cost of the moulds

Source: JHM Technologies, Inc.
Ecology and safety as a driving force in the development of vehicles.

Radom, 2-15/3/2008, Poland

Thermosetting based composites

Car components made from RTM (1)

Oporto light train panels

One piece floor structure

RTM window frames for a leading bus manufacturer.
Thermosetting based composites

Car componentes made from RTM (2)

floorstructure

Space-Frame structure (hollow)

Car bonnet
Thermosetting based composites

Automotive market: short cycle RTM (High speed RTM)

Automotive market: short cycle RTM (High speed RTM)

Schematic of high-speed RTM process

Source: J. S. Colton, Georgia Institute of Technology.
SCRIMP - Seemann Composites Resin Infusion Molding Process

SCRIMP is a resin transfer moulding process that uses a vacuum to pull liquid resin into a dry lay-up and is used for making very high quality, repeatable composite parts. The SCRIMP technology serves a variety of applications and is compatible with all types of fibre reinforcements and resin matrices commonly used today. It is suited to build large-scale structural composite parts where high strength, durability and light weight are critical.

RIM – Reaction Injection Moulding

Two liquid reactants - polyisocyanate component and resin mixture - are held in separate temperature controlled feed tanks. From these tanks, the polyol and isocyanate are fed through supply lines to metering units that precisely meter the reactants, as high pressure, to the mix-head. When injection begins and valves in the mix-head open, the liquid reactants enter a chamber in the mix-head where they are intensively mixed. From the mix chamber, the liquid flows into the mould at approximately atmospheric pressure and undergoes an exothermic chemical reaction, forming the polyurethane polymer in the mould. An average mould may be filled in one second or less and be ready for demolding in 30-60 seconds.

RIM parts can cost 30% less than the RTM or steel parts, mostly because of a short cycle-time.

SRIM – Structural RIM

Low-viscosity polyurethane RIM systems can be injected into a mold through glass mats or preformed glass fiber mats to produce very stiff, high-strength structural RIM (SRIM) parts. Often, SRIM is called a two-step process:

• The operator first places the preformed glass fiber mat into the open mold.
• Then, the mold is closed and the polyurethane resin is injected into the mold, where it permeates and surrounds the glass fiber mat to form the part.

SRIM is most often used in demanding applications where the part is subjected to heavy loads and punishing use

Chevrolet Silverado pickup truck box and tailgate (SRIM)

DaimlerChrysler minivan load floor (weight savings versus a steel panel)

Comparative design guidelines for RTM, open and compression moulding

<table>
<thead>
<tr>
<th>Design parameter</th>
<th>Resin-transfer molding</th>
<th>Open molding</th>
<th>Compression molding</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Sprayup</td>
<td>Hand layup</td>
</tr>
<tr>
<td>Minimum inside radius, inches</td>
<td>1/4</td>
<td>1/4</td>
<td>1/4</td>
</tr>
<tr>
<td>Molded-in holes</td>
<td>No</td>
<td>Large</td>
<td>Large</td>
</tr>
<tr>
<td>In-mold trimming</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Core pull and slides</td>
<td>Difficult</td>
<td>Difficult</td>
<td>Difficult</td>
</tr>
<tr>
<td>Undercuts</td>
<td>Difficult</td>
<td>Difficult</td>
<td>Difficult</td>
</tr>
<tr>
<td>Minimum recommended draft, deg</td>
<td>2 to 3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Minimum practical thickness, inches</td>
<td>0.080</td>
<td>0.060</td>
<td>0.060</td>
</tr>
<tr>
<td>Maximum practical thickness, inches</td>
<td>0.500</td>
<td>No limit</td>
<td>No limit</td>
</tr>
<tr>
<td>Normal thickness variation, inches</td>
<td>± 0.010</td>
<td>± 0.020</td>
<td>± 0.020</td>
</tr>
<tr>
<td>Maximum thickness buildup, heavy buildup, ratio</td>
<td>2:1</td>
<td>As required</td>
<td>As required</td>
</tr>
<tr>
<td>Corrugated sections</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Metal inserts</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Bosses</td>
<td>Difficult</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Ribs</td>
<td>Difficult</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Hat section</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Raised numbers</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Finished surfaces</td>
<td>Two</td>
<td>One</td>
<td>One</td>
</tr>
</tbody>
</table>

Source: Owens-Corning Fiberglas
Filament winding

Increasing demand for pressure vessels in the automotive sector

- **Traditional** pressure vessels (350 bar)-natural gas vehicles

- **Hydrogen** vessels used in car prototypes (700 bar working pressure: burst pressure of 2100 bar)

Fundamentally the process involves winding roving or tow around a mandrel. The winding angle ranges from nearly axial, or longitudinal ($0^\circ$, axial, can be obtained in special winding operations) to hoop, or circumferential ($90^\circ$). It uses CNC controlled machines.

Source: J. S. Colton, Georgia Institute of Technology.
- Curing cycles with pressure, temperature and vacuum
- Work with carbon-epoxy glass-epoxy pre-pregs in a clean room

Cure cycle

Typical autoclave bag assembly
Ecology and safety as a driving force in the development of vehicles
Radom, 2-15/3/2008, Poland

Thermosetting based composites

Automotive products made by autoclave

Racing seats

Carbon fibre rear wheel

F1 structural component

F1 carbon/epoxy structure

Source: Renault F1 Team on Developing Composite Racecars In 6 Months, LWV5 Conference October 6, 2003.

The pultrusion process is a highly automated continuous fibre laminating process producing high fibre volume profiles with a constant cross section.
Thermoplastic composites are increasing in the automotive market

- **Advantages**: excellent toughness, durability and damping properties, possibility of processing without chemical reactions, recyclability, reshaping and reparable
- The **high viscosity** of thermoplastic melts makes the impregnation of continuous fibres quite difficult, thus restricting the utilisation of these materials in commercial applications

Darcy law

\[ u_p = \frac{dx}{dt} = \frac{K}{\eta} \frac{dP}{dx} \]

- **\( U_p \)**, polymer flow velocity
- **\( K \)**, fibre permeability
- **\( \eta \)**, polymer viscosity
- **\( P \)**, applied polymer pressure

\[ t_{imp} = \frac{\eta D_p^2}{2KP} \]

**\( t_{imp} \)**, impregnation time
Ecology and safety as a driving force in the development of vehicles
Radom, 2-15/3/2008, Poland

Thermoplastic based composites

Raw material base + semifinished products

Polypropylene

Glasfibres

GMT/GMTex

LFT-granulate

LFT-plastificate

Thermoplastic based composites

Thermoplastic polymers

- High performance:
  - High temperature applications
  - Defence
  - Aerospace

- Engineering:
  - Sport
  - Medical
  - Automotive

- Standard:
  - Appliances
  - Construction

PRIMOSPIRE® , (self reinforced polymer, from Solvay advanced polymers)

<table>
<thead>
<tr>
<th>Property</th>
<th>ASTM Method</th>
<th>SI Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>D 638</td>
<td>207 MPa</td>
</tr>
<tr>
<td>Tensile Modulus</td>
<td>D 638</td>
<td>8.3 GPa</td>
</tr>
<tr>
<td>Flexural Strength</td>
<td>D 790</td>
<td>310 MPa</td>
</tr>
<tr>
<td>Flexural Modulus</td>
<td>D 790</td>
<td>8.3 GPa</td>
</tr>
<tr>
<td>Compressive Strength at Yield</td>
<td>D 305</td>
<td>0.4 MPa</td>
</tr>
</tbody>
</table>

Thermoplastic based composites

Car components made from thermoplastic composites

Electronic control box  
Frontend  
Battery tray  
Sill finisher  
Hatchback door  
Spare wheel pan  
Instrument panel  
Bumper beam  
Noise shield  
Seat structure  
Underbody panel

Long-Fiber Technology (LFT)

The G-LFT process incorporates fibre glass rovings into an impregnation centre with any of dozens of available base polymers. After the glass is incorporated with the resin, the compound is cooled and then pulled into a chopper that cuts it into pellets (current length=11 mm)

Processing: injection moulding or compression moulding

G-LFT (Granular Long-Fiber Technology)

D-LFT (Direct Long-Fiber Technology)

D-LFT enables processors to take advantage of a “one-step” process in which the resin, fiber glass and additives are directly integrated into the moulding or part-extrusion process.
It achieves cost, time and processing savings by integrating the compounding step into the final parts molding process.
The final composite then exhibits exceptional mechanical properties because fiber integrity and length are maintained better than in traditional thermoplastic processes.

Source: Dieffenbacher GmbH & Co.
LFT-D-ILC Applications

- Front end carrier
- Fiat Stilo

- Material: LFT-D 30 PP
- Weight: 3,5 kg
  10 % of recycled material
- Dimensions: 1490 x 550 x 330 mm
- Cycle time: 35 sec
- Hydraulic high-speed press, type DYG 1800/1500 AS, including active servo-controlled parallel motion system
- Extruder capacity: 480 kg/h

Source: Dieffenbacher GmbH & Co.
Thermoplastic based composites

Car componentes made from LFT (2)

Instrument panel carrier
Mercedes E - Class

Source: Dieffenbacher GmbH & Co.
Thermoplastic based composites

Car componentes made from LFT (3)

Front End Carrier

VW Passat

Fiat Stilo

Skoda Fabia

Source: Dieffenbacher GmbH & Co.
**GMT - Glass Mat Reinforced Thermoplastic**

**GMT** is a glass mat-reinforced thermoplastic material, generally with a PP matrix, which is manufactured to a semi-finished product.

After heating above the polymer’s melting point, the GMT semi-finished sheets can be flow moulded into final complex components. This is achieved by the high mobility of the glass mats. Its high impact strength and rigidity with relatively low weight are the characteristic features of the GMT material.
Ecology and safety as a driving force in the development of vehicles
Radom, 2-15/3/2008, Poland

GMT - Press forming
* Simple parts with uniform wall
* Lower pressure required (<
* No flow
* Material waste +/- 15% (shape
* Lower tooling cost - no telescoping

GMT - Flow molding (>95% of components)
* Complex parts with varying wall thicknesses and
* Higher molding pressure (>180 bar)
* No material waste
* Tool with telescoping

Thermoplastic based composites

Car components made from GMT (1)

Application: Spare Wheel Well (SWW)
Vehicle: DC W203 C-class
Introduction: April 2000 (FC)
Volume: 280,000/yr
Location: Sindelfingen, Bremen
Moulder(s): Rüters Automotive, König/Peine
Weight: 4.7 kgs
Material: Hybridge of Azdel 30% Random and 40% Uni GMT
Specifics: Adhesively bonded in BIW
- Uni material because of car crash requirement
- Low weight, no corrosion, part integration

Thermoplastic based composites

Car components made from GMT (2)

- **Application**: Underbody Shields (UBV)
- **Vehicle**: DC W203 C-Class
- **Introduction**: April 2000 (FC)
- **Volume**: 280,000/yr
- **Location**: Sindelfingen, Bremen
- **Moulder(s)**: Polynorm Roosendaal
- **Weight**: 4 kg/car, L+R part
- **Material**: Azdel 30% Random GMT
- **Specifics**: Replacing PVC Underbody Coating
  - No corrosion, improving aerodynamics

*Source: 1st EATC meeting, Frankfurt, 2000.*
Car components made from GMT (3)

Material:
PP-GM40 (Polypropylene with 40% by weight of random glass fibre)

Part Information:
- Weight: 3.5 kg
- Dimension: 1270 mm x 495 mm x 230 mm
- Thickness: 2 to 6 mm
- Functions:
  - Support of radiator, bonnet locker
  - Controlled energy absorption

Key Technologies:
- Flow molding (compression-tool with shear edges)
- All openings and holes stamped after molding
- Inserts and steel bushes pressed in direct after molding
- Cycle time: 45 s

Advantages:
- High stiffness and dimensional stability
- Complete pre-assembled unit (mounted to the car body with all front devices included)
- Recyclability
- Weight reduction
- Corrosion resistance
- Good fatigue behaviour up to 100°C
Thermoplastic based composites

CFRT - Continuous Fibre Reinforced Thermoplastic

FIT - Fibre Imprégné de Thermoplastique

Commingled fibres
(Twintex from Saint Gobain, Vetrotex)

Towpreg (ISEP, INEGI)

Thermoplastic layer

towpreg

glass fibres

polymer fibres

polymer particles

fibres
Thermoplastic based composites

Towpreg production

Schematic diagram of the powder-coating line

Picture of the prototype powder coating line

Source: Silva, J. et al
Thermoplastic based composites

CFRT – Processing technology: Filament winding

Schematic diagram of a thermoplastic filament winding processing technology

Simulation of fibre patterns for a 30 ° winding angle for a pressure vessel component

Source: Silva, João et al.
Thermoplastic based composites

Car componentes made from CFRT composites

Source: Silva et al & AMTROL-ALFA.
Recent advances in CFRT composites processing for the automotive industry

Consolidation:
Preform Compacted
Hot Air Melts Binder

Stabilization:
Cold Air Freezes Binder
and Sets Preform

De-Molding:
Preform Removed from Tool

Glass Deposition:
Glass and Binder
Applied to Screen
via Robot Routines

F3P Process Schematic

Source: University of Nottingham & GM.
F3P Advantages

- Low cost - utilises raw materials in their cheapest form
- Minimal wastage (<3%)
- Fully automated robotic operation
- Fast cycle – high part throughput
- Produces consolidated net-shape preform
- Can produce complex shapes
- Consistent areal density
- Local variations in part thickness or volume fraction easily accomplished

Source: University of Nottingham & GM.
Thermoplastic composite ‘sandwich’ concept

- The patented **Sandwiform** consists of a honeycombed cellular core positioned between two thermoplastic skins reinforced with glass and polypropylene.
- Vehicle applications for Sandwiform include cargo load floors.

**Source:** Automotive Engineering, SAE international, 2007.
Natural fibres: low price and ecological. Can be used as fillers or reinforcement in polymeric composites

- The most used natural fibre in Europe is flax
- The most important processing technology is compression moulding

**Plant fibres classification**

- **Bast fibres**
  - flax
  - hemp
  - jute
  - kenaf
  - rami
- **Leaf fibres**
  - agaves e.g. sisal, curaua
- **Seed fibres**
  - cotton
  - kapok
- **Fruit fibres**
  - coconut
- **Wood fibres**
  - e.g. pinewood

**Compression Molding** of
- rosinated plant fiber mats
- plant fiber/PP hybrid mats
- NMT (Natural fiber Mat reinforced Thermoplastics) comparable to GMT (Glass fiber Mat reinforced Thermoplastics)
- EXPRESS Process (extrusion-compression molding)

- Structural Reaction Injection Molding (S-RIM)
- Injection Molding with short fiber reinforcement

Ecology and safety as a driving force in the development of vehicles

Radom, 2-15/3/2008, Poland

**Natural fibre composites**

Car components made from natural fibre composite

- Natural fibre composite components of Mercedes-Benz E Class. *(source: Daimler Chrysler)*

- Flax/epoxy, BMW, *(source: Nova-institute, Cologne, Germany)*
Performance improvements of car components and functionalities achievable by nanotechnology

**NANOTECHNOLOGIES**

**Lighter** car bodies without compromises to the stiffness and crash resistance means less material and indirectly less fuel consumption.

**Nanocomposites** based on various metal or plastic matrix material strengthened by metal or ceramic nanoparticles or nanoplatelets can improve the strength by 100%.

However, a real breakthrough will occur when carbon **Bucky fibers** will become available in huge quantities. These giant one-dimensional molecule promises a tensile strength of 150 GPa, about 50 times that of steel with 1/5th of the weight.

Even a polymer-nanofiber nanocomposite would yield considerably thinner, stiffer and lighter parts for cars. That opens a huge research field for the next years.

---

**Source:** Mate Hartmut, Presting future nanotechnology developments for automotive applications, Daimler Chrysler Research, 2003.
Future materials & technologies

Nanomaterials

Performance resins enhanced by nanotechnology

**Part:** Bumpers  
**Material:** Customized PP for Honda  
**Volume:** >12,000,000 lbs  
**Nano-benefit:**  
- High stiffness = thin wall (light weight)  
- Low filler % = good impact (high quality)  
- Low filler % = low density (light weight)  
- Conductive? = primer elimination (low cost)

**Part:** Truck Bed  
**Material:** Customized GF SMC for Honda  
**Volume:** >5,500,000 lbs  
**Nano-benefit:**  
- Glass elimination = improved recyclability  
- High stiffness = thin wall (light weight)  
- Low filler % = good impact (high quality)  
- Low filler % = low density (light weight)  
- Conductive? = Static dissipation

Source: Honda.
The material predominantly used in REVOLUTION passenger safety cell is LFT. (intermediate modulus carbon fibre/PA matrix)

Mass comparison of REVOLUTION with a conventional benchmark vehicle

<table>
<thead>
<tr>
<th>System</th>
<th>Benchmark mass (kg)</th>
<th>Revolution mass (kg)</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure</td>
<td>430</td>
<td>186.5</td>
<td>-57 %</td>
</tr>
<tr>
<td>Propulsion</td>
<td>468</td>
<td>288.3</td>
<td>-38 %</td>
</tr>
<tr>
<td>Chassis</td>
<td>306</td>
<td>201.2</td>
<td>-34 %</td>
</tr>
<tr>
<td>Electrical</td>
<td>72</td>
<td>33.4</td>
<td>-54 %</td>
</tr>
<tr>
<td>Trim</td>
<td>513</td>
<td>143.2</td>
<td>-72 %</td>
</tr>
<tr>
<td>Fluids</td>
<td>11</td>
<td>4.1</td>
<td>-63 %</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,800</strong></td>
<td><strong>856.6</strong></td>
<td><strong>-52 %</strong></td>
</tr>
</tbody>
</table>

THE END

Penny-farthing bicycle

Source: Appleton's Cyclopaedia of Applied Mechanics, 1892.